Associations Between Executive Cognitive Functioning in Early Adolescence and Alcohol-Related Problems in Young Adulthood: Results from a Prospective, Longitudinal Study

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of the Arts

Approved October 2017 by the
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ARIZONA STATE UNIVERSITY

December 2017

ABSTRACT

Poor executive cognitive functioning (ECF) is associated with a variety of alcohol-related problems, however, it is not known whether poor ECF precedes the onset of heavy drinking. Establishing the temporal precedence of poor ECF may have implications for our understanding of the development of Alcohol Use Disorder (AUD). The present study tests associations between early-adolescent ECF and young-adult risky drinking and alcohol-related problems in a prospective study of youth followed to young adulthood. Participants completed three ECF tasks at ages 11-14 and reported on their risky drinking and alcohol-related problems at ages 18-24. A latent ECF factor was created to determine whether early-adolescent ECF was associated with drinking outcomes after controlling for relevant covariates (e.g., age, sex, family history of AUD). Early-adolescent ECF, as measured by a latent factor, was unrelated to young-adult alcohol misuse and alcohol-related problems. However, sensitivity analyses revealed that an individual ECF task tapping response inhibition predicted young-adult peak drinks in a day. Present findings suggest that ECF is not a robust predictor of risky drinking or alcohol-related problems, and that this relation may be specific to the ECF component of response inhibition.

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Poor executive cognitive functioning (ECF) is gaining attention as a potential risk factor for the development of alcohol-related problems (Boelema et al., 2016; Day, Kahler, Ahern, & Clark, 2015; Khurana et al., 2013; Litten, 2015; Peeters et al., 2015; Sher, 2015; Squeglia, Jacobus, Nguyen-Louie, & Tapert, 2014). ECF is an umbrella construct for a set of component cognitive processes required to monitor, plan, initiate, and maintain goal-directed behavior (Blume and Marlatt, 2009). Although there is no consensus regarding the organization of ECF, a well-supported model postulates that ECF is comprised of three component processes: updating (monitoring the contents of working memory), shifting (switching attention between tasks), and inhibition (suppressing prepotent responses) (Miyake, Friedman, Emerson, Witzki, & Howeter, 2000; Miyake & Friedman, 2012). Impairment of these ECF components could increase risk for maladaptive drinking behavior. For example, an individual with updating deficits may fail to recognize cues preceding or during a drinking episode that signal an impending problem (e.g., drunkenness, physical fights); shifting deficits could further undermine this person's ability to divert attention away from alcohol cues; and inhibition deficits could make it difficult for this person to resist an urge to go to a party, drink more than planned, or engage in risky behavior while intoxicated. Indeed, research shows that poor ECF is associated with a variety of alcohol-related problems, including aggressive behavior and alcohol dependence (Giancola, 2004; Hildebrandt, Brokate, Eling, & Lanz, 2004). However, most studies of ECF and alcohol-related problems are cross-sectional. Prospective studies are needed to establish the temporal precedence of poor ECF. This is particularly important as ECF was recently proposed as a candidate domain for an

"Alcohol Addiction RDoC," under the hypothesis that poor ECF represents an underlying risk factor for alcohol use disorder (AUD) (Litten, 2015).

Cross-sectional studies show that adults with alcohol dependence exhibit general ECF deficits, as well as specific deficits in updating, shifting, and inhibition, when compared with non-dependent adults (Bjork, Hommer, Grant, & Danube, 2004; Hildebrandt, Brokate, Eling, & Lanz, 2004; Kamarajan et al., 2005; Nowakowska, Jabłkowska, & Borkowska, 2008; Sullivan, Rosenbloom, & Pfefferbaum, 2000). For example, detoxified men with alcohol dependence were found to perform worse than non-dependent men on a composite measure of ECF, even after controlling for group differences in education and estimated premorbid intelligence (IQ) (Sullivan, Rosenbloom, & Pfefferbaum, 2000). Another study found that, relative to non-dependent adults, adults with alcohol dependence showed ECF deficits on an updating task (the N-back test) and shifting task (the Wisconsin Card Sorting Test) even after a year of abstinence (Nowakowska, Jabłkowska, & Borkowska, 2008). Moreover, several studies have found that adults with alcohol dependence perform poorly compared with non-dependent adults on various measures of inhibition (Bjork et al., 2004; Goudriaan et al., 2006; Kamarajan et al., 2005).

Adolescents with alcohol dependence also show ECF deficits, though, compared with adults, associations seem to be smaller and less consistent (Brown, Tapert, Grandholm, & Delis, 2000; Giancola, Mezzich, & Tarter, 1998; Moss, Kirisci, Gordon, & Tarter, 1994; Nigg, et al., 2006). One study found that girls ages 14-18 with alcohol and other substance use disorders scored significantly lower than comparison girls on a composite measure of ECF after controlling for socioeconomic status and age (Giancola,

Mezzich, & Tarter, 1998). In another study, adolescents ages 15-17 with alcohol dependence performed slightly (though non-significantly) worse than comparison adolescents on the Wisconsin Card Sorting Test, Trail Making Test, and the Backward Digit Span task (Brown, et al., 2000). Furthermore, in a study of boys ages 12-17, inhibition deficits on the Stop Signal Task were associated with lifetime alcohol-related problems even after controlling for low IQ, externalizing symptoms, and parental alcoholism (Nigg et al., 2006). Other ECF measures tapping other ECF components (e.g., Wisconsin Card Sorting Test, which tests shifting) were not associated with alcohol-related problems, however (Nigg, et al., 2006).

Most cross-sectional studies have focused on samples of patients with alcohol dependence, but some evidence suggests ECF deficits are apparent among non-dependent drinkers (Houston et al., 2014; Nederkoorn, Baltus, Guerrieri, and Wiers, 2009; Parada et al., 2012; Patrick, Blair, & Maggs, 2008). For example, in a community sample of adults, individuals with higher levels of alcohol consumption performed worse on tasks of inhibition and shifting after controlling for age, gender, education, and drug use (Houston et al., 2014). Some, but not all, cross-sectional studies have also shown associations between young-adult binge drinking or heavy drinking and ECF deficits (Hartley, Elsebagh, & File, 2004; Montgomery, Fisk, Murphy, Ryland, & Hilton, 2012; Nederkoorn et al., 2009; Parada et al., 2012; Patrick, Blair, & Maggs, 2008; Townshend & Duka, 2005). For example, in one study of binge drinking in college students, students who binge drank performed worse than students who did not binge drink on tasks of updating (Backward Digit Span test) and inhibition (Self-Ordered Pointing Task) (Parada et al., 2012). In another study, young-adult binge-drinking women showed inhibition

deficits on the Vigilance Task but young-adult binge-drinking men did not (Townshend & Duka, 2005). In addition, a few cross-sectional studies of heavy drinking college students have found evidence of updating deficits among heavy drinkers (Ellingson, Fleming, Vergés, Bartholow, & Sher, 2014; Gil-Hernandez & Garcia-Moreno, 2016; Patrick, Blair, & Maggs, 2008). Taken together, cross-sectional studies suggest an association between poor ECF and alcohol misuse, but this relation may depend on the severity of alcohol misuse in the sample, the specific ECF component assessed, and the specific tasks used to measure ECF ability (Day et al., 2015).

Several hypotheses have been advanced to explain the association between ECF and alcohol misuse reported in cross-sectional studies. First, ECF and alcohol misuse may be correlated due to shared genetic and environmental influences (e.g., family history of alcoholism, fetal alcohol syndrome, polysubstance use, psychiatric comorbidity). In support of this hypothesis, family history of alcoholism is a known risk factor for alcohol misuse (Chassin, Rogosch, & Barrera, 1991; Grant, 1998), and some evidence suggests that children with a family history of alcoholism show ECF deficits prior to the onset of drinking (Gierski et al., 2013; Nigg et al., 2004; Giancola, Moss, Martin, Kirisci, & Tarter, 1996). Not all studies find this association, however (Handley, Chassin, Haller, Bountress, Dandreaux, 2011; Stevens, Kaplan, & Hesselbrock, 2003). Additional evidence comes from studies showing that externalizing disorders, which are highly prevalent in individuals who misuse alcohol (Chan, Dennis, & Funk, 2008; Kessler et al., 1997; Rohde, Lewinsohn, & Seeley, 1996), are associated with ECF deficits (Giancola & Mezzich, 2000; Marchetta, Hurks, Krabbendam, & Jolles, 2008; Sergeant, Geurts, & Oosterlaan, 2002), and a twin study showed that the association

between externalizing psychopathology and ECF deficits could be explained by common genetic factors (Young et al., 2009).

A second hypothesis posits that heavy drinking leads to ECF impairment over time (Field, Schoenmakers, & Wiers, 2008). This is supported by animal models showing that adolescent rats exposed to alcohol exhibit ECF-related impairment in adulthood on tasks of decision-making, shifting, and spatial working memory (Broadwater and Spear, 2013; Schindler, Tsutsui, & Clark, 2014; Sircar and Sircar, 2005). Further, longitudinal studies of alcohol-dependent adult men suggest ECF improvement following a brief period of abstinence (Loeber et al., 2010; Mann, Gunther, Stetter, & Ackermann, 1999). However, prospective studies tracking ECF from early adolescence to late adolescence have not consistently demonstrated alcohol-related decline in ECF, which might indicate that adolescents exposed to relatively low levels of alcohol do not show ECF deficits (Boelema et al., 2014; Nguyen-Louie et al., 2015; Squeglia, Spadoni, Infante, Myers, & Tapert, 2009).

A third possibility is that ECF deficits are causally related to the development of alcohol misuse and related problems. In this case, we would expect that ECF deficits precede and increase risk for alcohol misuse and related problems, over and above potential confounding factors, such as family history of alcoholism. Only a handful of prospective studies have examined ECF as a predictor of alcohol misuse, and existing studies have produced mixed findings (Boelema et al., 2016; Khurana et al., 2013; Norman et al., 2011; Peeters et al., 2015; Squeglia, Jacobus, Nguyen-Louie, & Tapert, 2014; Squeglia, Pulido, Wetterhill, Jacobus, & Brown, 2012;Wetterhill, Castro, Squeglia, & Tapert, 2013; Wetterhill, Squeglia, Tang, & Tapert, 2013). Several prospective studies

have not found evidence of an association between ECF deficits and subsequent alcohol misuse (Boelema et al., 2016; Norman et al., 2011; Squeglia et al., 2013; Wetterhill et al., 2013; Wetterhill et al., 2013). For example, in a series of five studies based on largely the same sample of youth, baseline ECF performance was generally not related to later alcohol consumption (Norman et al., 2011; Squeglia et al., 2012; Squeglia et al., 2014; Wetterhill et al., 2013; Wetterhill et al., 2013). However, four of the five studies contained small samples of heavy-drinking adolescents (group sizes ranged from n=17 to n=21), and null findings may have been attributable to low power to detect effects (Norman et al., 2011; Squeglia et al., 2012; Wetterhill et al., 2013; Wetterhill et al., 2013). When the sample was expanded (N=175; 105 substance use transitioners, 70 non-users), adolescents ages 12-14 who performed poorly on a baseline measure of inhibition (Color-Word Interference) reported more drinking days and a greater number of drinks on a single occasion at ages 17-18, over and above covariates including family history of AUD, externalizing behavior, and academic achievement (Squeglia et al., 2014). Still, all other cognitive measures, including tests of other executive cognitive functions (e.g., updating), failed to predict alcohol use (Squeglia et al., 2014). Null findings were also reported in a school-based sample of 1,596 Dutch adolescents (Boelema et al., 2016). That is, ECF at age 11 did not predict risk of alcohol abuse or dependence at age 19 (Boelema et al., 2016). Although not limited by sample size (399 adolescents developed an alcohol-use disorder), the basic tasks used in the Dutch study (reaction time tasks) may not have been sensitive enough to detect subtle, pre-existing ECF deficits (Boelema et al., 2016).

In contrast, several prospective longitudinal studies have found evidence of an association between ECF deficits and subsequent alcohol use (Khurana et al., 2013; Peeters et al., 2015; Squeglia et al., 2014). In a different Dutch school-based sample, updating and inhibition deficits at ages 12-15 predicted onset of first drink two years later (Peeters et al., 2015). However, the majority of participants were recruited from specialized schools for children with behavioral problems, and the study did not control for behavioral disorders (Peeters et al., 2015). Finally, in another community sample of 10-12 year olds followed annually for four years, poor updating ability at baseline, as measured by a composite of working memory tasks, predicted increased frequency of drinking episodes across the four years (Khurana et al., 2013).

Our review of prospective studies suggests that findings are inconsistent, and several methodological factors may explain the inconsistencies. The first is sample size. Half of the prospective studies conducted to date were made up of small samples (e.g., Norman et al., 2011: N = 38; Squeglia et al., 2012: N = 40; Wetterhill et al., 2013: N = 60; Wetterhill et al., 2013: N = 40), which reduces statistical power to detect associations. Second, as has been noted recently, there are concerns about the psychometric properties of ECF tasks (Sher, 2015). The intercorrelations among ECF tasks, even among those designed to assess the same ECF component (e.g., inhibition), are generally low (Burgess, 1997; Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Fillmore and Weafer, 2013). Low intercorrelations may be attributable to the "task impurity problem," whereby scores on individual tasks are influenced by task-specific demands (Miyake & Friedman, 2012). No single ECF task provides a process-pure measure of the ECF construct (Miyake, Friedman, Emerson, Witzki, & Howeter, 2000). Thus, non-ECF

processes (e.g., visuospatial processing, speed of articulation) may introduce too much error variance to accurately assess ECF at the individual task level (Miyake et al., 2000; Miyake & Friedman, 2012). To address this problem, Miyake & Friedman (2012) recommend a latent-variable approach. By selecting several tasks that tap the same underlying construct but involve different task demands, one can create a latent variable to partial out non-ECF variance and provide a more task-independent estimate of ability (Miyake & Friedman, 2012).

Finally, although a handful of prospective studies have examined the association between ECF and alcohol use or misuse, only one has examined the association between ECF and alcohol-related problems (Boelema et al., 2016). Unlike measures of alcohol misuse, measures of alcohol-related problems tap risk-taking behavior while intoxicated (e.g., drunk driving). Because low ECF is associated with a host of risk-taking behaviors (e.g., unsafe driving) (Giancola, Tarter, Pelham, & Moss, 1996; Steinberg, 2008, Pharo et al., 2011), it is important to evaluate low ECF as a risk factor for alcohol-related problems specifically. Determining whether low ECF represents a risk factor for alcohol-related problems could be particularly important for prevention and early intervention efforts.

The purpose of the present study was to test associations between early-adolescent ECF and young-adult risky drinking and alcohol-related problems in a prospective study of youth followed to young adulthood. To address the limitations outlined above, we utilized a latent ECF factor, and we assessed alcohol misuse and alcohol-related problems in young adulthood.

Method

Participants

Participants were drawn from a large, multigenerational prospective longitudinal study of familial alcoholism (Chassin, Barrera, Bech, & Kossak-Fuller, 1992). Data collection was initiated in 1988 when families with at least 1 parent with an AUD and demographically-matched comparison families were recruited to the study. Full details about sample ascertainment are reported in Chassin et al. (1992). The parents are referred to as generation 1 and children as generation 2 participants. When the generation 2 participants had grown up, their children (generation 3) were recruited to the study. The current study focuses on generation 3 participants. A total of 606 generation 3 youth ages 10-17 participated in an assessment that took place from 2006-2011.

Of the 606 generation 3 participants, those who were at least 11 years old (n = 556) were eligible to complete a battery of neuropsychological tasks. A total of 412 generation 3 participants were administered a battery of neuropsychological tasks, and 405 had complete data on three measures of ECF. Of those 405 participants, the current study focuses only on those participants who were ages 11-14 at the time of the ECF tests (n = 325). We elected to focus on youth ages 11-14 to capture the developmental period of early adolescence, a period prior to initiation of alcohol use. Of these 325 youth, 2 had already initiated alcohol use at the time of the ECF assessment and were excluded from analyses. Of the remaining 323 youth, 232 took part in a follow-up survey of young-adult drinking and alcohol-related problems when they were 18-24 years of age (M age = 19.69, SD = 1.72). **Figure 1** depicts study flow.

In attrition analyses, we selected all participants who were age 11-14 at the time of the ECF assessment and had data on all three ECF tasks available (**Supplemental**

Table 1). Then, we compared those who had (n = 232) and had not (n = 91) completed the young-adult survey on demographic factors, family history of alcohol and drug use disorders, adolescent externalizing behavior at age 11-14, IQ at age 11-14, and ECF at age 11-14. We identified several differences between included and excluded participants. Participants who were excluded from this report had lower IQ and performed worse on the Letter-Number Sequencing and Immediate Memory Task in early adolescence. The differential attrition of lower-ECF individuals may attenuate the hypothesized association between ECF and risky drinking and alcohol-related problems.

Measures

Executive Cognitive Functioning Tasks (ages 11-14)

We assessed ECF at ages 11-14 using three tasks: Letter-Number Sequencing (LNS – a test of verbal updating), Matrix Span Task (MST – a test of spatial updating), and Immediate Memory Task (IMT – a test of response inhibition). We describe each task below. We used the three ECF tasks to create a latent ECF variable, as previous research has shown that tasks of updating and response inhibition consistently load onto a single factor (Miyake & Friedman, 2012). We conducted a confirmatory factor analysis of the three ECF tasks, and consistent with previous research in this sample (Jensen, 2016), factor loadings for each of the three ECF tasks were moderate to large, with standardized factor loadings of 0.56, 0.72, and 0.44 for LNS, MST, and IMT, respectively. Model fit was not available because the model was fully saturated.

We tested whether factor loadings were equivalent across boys and girls. We estimated the unconstrained model of ECF simultaneously for girls and boys, and then compared it to a constrained model in which factor loadings were held equal across sex.

The fit of the constrained model was not significantly worse than the fit of the unconstrained model ($\Delta\chi^2$ (3, N = 232) = 4.81, p = 0.19), indicating factor loading invariance for each of the three indicators of the ECF construct.

Letter-Number Sequencing (Verbal Updating). The Letter-Number Sequencing (LNS) subtest of the Wechsler Intelligence Scale for Children was used to assess verbal updating (WISC-IV; *Wechsler, 2003).* Participants were asked to listen to a combination of numbers and letters and recall the numbers in ascending order followed by the letters in alphabetical order. The task progressed in difficulty with each subsequent trial. The total number of trials completed was summed to create a verbal updating score.

Matrix Span Task (Spatial Updating). The Matrix Span Task (MST) was used to assess spatial updating (Conway et al., 2005). Participants were presented with a series of 4 x 4 matrices on a computer screen. One cell of each matrix was highlighted and participants were asked to memorize the location of highlighted cells as a series of 2-5 matrices were presented. Following the completion of a series, participants were cued to recall the location of each highlighted cell on a response sheet. Partial credit scoring, where credit is given for individual correct answers in a series, has been found to be most sensitive to differences in task performance (Conway et al., 2005). Thus, scores were calculated based on the proportion of units within an item recalled correctly, averaged across trials.

Immediate Memory Task (Response Inhibition). The Immediate Memory Task (IMT) was used to assess response inhibition (IMT; Dougherty, Marsh, & Mathias, 2002). Participants were presented with a series of five-digit numbers that appeared in one-second intervals on a computer screen. For each presentation, participants were

asked to indicate if a given number exactly matched the previous number by pressing a button. A third of the trials were followed by an identical five-digit number (target trials), a third were followed by a five-digit number in which every number differed (foil trials), and a third were followed by a five-digit number in which only one number differed (catch trials). The ratio of catch trials to target trials responded to was used to create a score of response inhibition. This item was reverse coded so that higher scores indicate higher response inhibition.

Young Adult Drinking (ages 18-24): Peak Drinks, Binge Drinking, and Alcohol-Related Problems

Peak Drinks. Peak number of drinks was assessed by asking participants: "What is the greatest number of drinks you have ever had in a whole day (24 hour period)? Recall a standard drink is 12 ounces of beer, 5 ounces of wine, or 1.5 ounces of hard liquor (straight or in a mixed drink)." Participants answered via free response.

Binge Drinking. Participants were asked how often in the past year they had "4 or more drinks" (women) or "5 or more drinks" (men) on a single occasion. Response options were: "Never" (1), "1-2 times" (2), "3-5 times" (3), "More than 5 times, but less than once a month" (4), "1-3 times a month" (5), "1-2 times a week" (6), "3-5 times a week" (7), and "Every day" (8).

Alcohol-Related Problems. Alcohol-related problems were indexed with a 24-item questionnaire. Example items are "How recently have you felt guilty about your drinking?," "How recently did your alcohol use cause you to get arrested for drunk driving?," "How recently did your alcohol use cause you to injure someone else?" For each item, participants were given a '1' if they had experienced the problem in their

lifetime, and a '0' if they had not. Total scores were calculated to indicate lifetime alcohol-related problems.

Covariates

Age, sex, and family history of AUD were included as covariates in all analyses. Additionally, we considered controlling for SES (total household income at time of ECF assessment) and ethnicity (Hispanic or non-Hispanic Caucasian). However, SES and ethnicity were not correlated with latent ECF (SES: r = -0.05, p = .57; ethnicity: r = -0.03, p = .68) or young-adult drinking outcomes (SES: *r*s for the three drinking outcomes ranged from -0.06 to 0.02, *ns*; ethnicity: *r*s for the three drinking outcomes ranged from 0.01 to 0.06, *ns*). Thus, SES and ethnicity were not included as covariates. Finally, because family history of drug use disorder (DUD), IQ, and childhood externalizing symptoms may be associated with both ECF and the development of risky drinking and alcohol-related problems, they too were considered as potential covariates.

Family History Density of AUDs. Family history of AUDs was captured with a family history density (FHD) score, a weighted composite of lifetime AUD diagnosis status for participant's biological parents and biological grandparents. Participant's parents and grandparents were interviewed repeatedly throughout the course of the study to obtain alcohol abuse and dependence information. Depending on the time of interview, either DSM-III-R, or both DSM-III-R and DSM-IV criteria were used to determine diagnosis status. Using all diagnostic criteria available across all waves of data collection, biological parent and grandparent lifetime alcohol diagnoses were coded based on any report of alcohol abuse or dependence, or no report of any alcohol abuse or dependence across all waves (Handley et al., 2011). The FHD score is the weighted sum of biological

parent and grandparent lifetime AUD diagnosis status, and scores range from 0 to 2. A higher score reflects a more dense family history of AUDs. Because each parent contributes half of their children's genetic material, parent lifetime AUD variables are weighted 0.5. Because each grandparent contributes a quarter of their grandchildren's genetic material, grandparent lifetime AUD variables are weighted 0.25. At minimum, the lifetime AUD diagnosis status of one biological parent and two grandparents had to be available to calculate an FHD score. The FHD was calculated by first applying the appropriate weights and summing the available lifetime alcohol variables. This score was then divided by the maximum possible weighted sum for the available lifetime AUD variables, and then multiplied by 2 to place the score in the 0 to 2 range.

Family History of DUDs. Family history of DUDs was assessed with a family history density (FHD) score, as described in the section above (Family History Density of AUDs). Depending on the time of interview, either DSM-III-R, or both DSM-III-R and DSM-IV criteria were used to determine diagnosis status. Using all diagnostic criteria available across all waves of data collection, biological parent and grandparent lifetime drug use disorder diagnoses were coded based on any report a drug use disorder, or no report of a drug use disorder across all waves.

IQ (ages 11-14). Participants completed the Kaufman Brief Intelligence Test when they were age 11-14 (K-BIT; Kaufman & Kaufman, 1990). The K-BIT score was a composite of the standard scores of two subtests: verbal intelligence, which included expressive vocabulary and word definitions, and nonverbal intelligence, which included a section of Matrices (Handley et al., 2011).

Early Adolescent Externalizing Problems (ages 11-14). When participants were 11-14 years old, parents reported on their child's externalizing behavior using the Child Behavior Checklist (CBCL; Achenbach, 1981). Scores from the parent reports on externalizing syndrome subscales (rule-breaking behavior and aggressive behavior) were added together to create externalizing summary scores for each participant.

Data Analysis

We tested the hypothesis that ECF in early adolescence (ages 11-14) predicts peak drinks, binge-drinking, and alcohol-related problems in young adulthood (ages 18-24) using structural equation modeling (SEM). All analyses controlled for age, sex, and family history of AUD, as the sample was enriched for children with a family history of AUD. **Figure 2** shows the basic model. If associations between ECF and alcohol outcomes were statistically significant after controlling for age, sex, and family history of AUD, covariates of family history of DUD, IQ, and early-adolescent externalizing problems were added to test whether associations between ECF and alcohol outcomes were independent of these factors. We tested for interactions between each covariate and ECF, and included interaction terms in the model if statistically significant. All analyses were conducted using Mplus software (Muthen & Muthen, 1998). Because some participants were siblings or cousins, observations were not independent. To account for the non-independence of observations, we used the CLUSTER function in Mplus, which adjusts for downwardly-biased standard errors.

Predicting Peak Drinks in a Day. Peak drinks in a day was positively skewed. We handled this in two complementary ways. In one approach, we recoded peak drinks into ordered categories (**Figure 3, Panel A**). We then analyzed the path from early-

adolescent ECF to young-adult peak drinks in a day using the CATEGORICAL function in Mplus, which treats peak drinks as an ordered categorical variable. In a second approach, we used the raw count outcome of peak drinks in a day (**Figure 3, Panel B**) and used negative binomial regression to account for the non-normal distribution. Incidence Rate Ratios (IRRs) are reported for the negative binomial models, which were calculated by exponentiating the negative binomial coefficient.

Predicting Past-Year Binge Drinking. Past-year binge drinking was positively skewed. This was due, in large part, to a considerable number (n = 120, 51.7%) of participants who never had a binge-drinking episode in the past year. Participants who did not binge drink in the past year comprised two subpopulations: one subpopulation of non-drinkers (n = 65, 28.0%) who were not at risk of binge drinking (structural zeros), and one subpopulation of drinkers (n = 55, 23.7%) who did not binge drink (sampling zeros). Because the ECF profile of these groups may be quite different, we removed the structural zeros from our analysis of past-year binge drinking (i.e., we removed the 65 participants who never drank; **Figure 4)**. We then analyzed the path from early-adolescent ECF to past-year binge drinking using the CATEGORICAL function in Mplus, which treats past-year binge-drinking as an ordered categorical variable. Because binge drinking is an ordered categorical outcome, we did not employ negative binomial modeling in our analysis of this association.

We ran additional analyses examining whether ECF predicted the odds of being a past-year binge drinker. A previous study found that low ECF predicted the odds of binge drinking initiation (Peeters et al., 2015), so it is possible that low ECF differentiates binge drinkers from non-binge drinkers. To examine this possibility, we recoded binge drinking

into a dichotomy of non-binge-drinkers (0) and binge-drinkers (1). Next, logistic regression was used to determine whether early-adolescent ECF predicted the odds of being a past-year binge drinker.

Predicting Alcohol-Related Problems. Lifetime alcohol-related problems was positively skewed. As with our analysis of peak drinks in a day, we handled this in two ways. In one approach, we removed those who have never had a drink (structural zeros) from the analysis and recoded alcohol-related problems into ordered categories (**Figure 5, Panel A**). The path from early-adolescent ECF to lifetime alcohol-related problems was analyzed using the CATEGORICAL function in Mplus. In a second approach, we analyzed the count outcome of lifetime alcohol-related problems (**Figure 5, Panel B**) using zero-inflated negative binomial regression. Zero-inflated negative binomial regression expresses count outcomes as a combination of two processes. The first process models structural zeros with a binary distribution. The second process models count values with a negative binomial distribution.

Results

Table 1 shows descriptive statistics on all study measures. **Supplemental Table 2** shows the zero-order correlations between ECF tasks and drinking outcomes. **Supplemental Table 3** shows the zero-order correlations between covariates and predictor/outcome variables. All covariate by ECF interactions were non-significant ($p > .05$), and thus, models did not include covariate interactions with ECF.

Does early-adolescent ECF predict peak number of drinks in a day in young adulthood?

Table 2 presents the prospective association between early-adolescent ECF and young-adult peak number of drinks in a day, after controlling for age, sex, and family history of AUD. First, we investigated whether early-adolescent ECF predicted peak drinks in a day, with peak drinks treated as an ordered categorical variable. The resulting model showed good model fit (RMSEA = 0.03, CFI = 0.99, and TLI = 0.98). ECF did not predict young-adult peak drinks in a day in this model (β = -0.13, p = .21). Next, we used negative binomial models to investigate whether early-adolescent ECF predicted a count variable of peak drinks in a day. To aid interpretation, the IRR is reported for this association. The IRR in Table 2 (IRR = 0.88) means that for every one-unit increase in latent ECF, there was a 12% decrease in peak number of drinks in a day. This decrease, however, was not statistically significant (p = .17).

Does early-adolescent ECF predict young-adult binge drinking?

Table 3 shows the prospective association between early-adolescent ECF and young-adult binge drinking among participants who had at least one lifetime drink (n = 167), after controlling for age, sex, and family history of AUD. Results showed that early-adolescent ECF was not a statistically significant predictor of young-adult binge drinking (β = 0.09, p = .51).

Table 4 shows the prospective association between early-adolescent ECF and the odds of binge drinking in the past year (N = 232), after controlling for age, sex, and family history of AUD. Early-adolescent ECF did not predict the odds of having one or more binge drinking episodes in the past year (OR = 0.81, p = .30).

Does early-adolescent ECF predict alcohol-related problems in young adulthood?

Table 5 presents the prospective association between early-adolescent ECF and young-adult alcohol-related problems. First, we treated young-adult alcohol-related problems as an ordered categorical variable and excluded participants who never had a drink from the analysis. ECF did not predict young-adult alcohol-related problems in this model ($\beta = 0.09$, $p = .49$). Next, we employed zero-inflated negative binomial regression to examine the association between ECF and the count outcome of alcohol-related problems in the full sample. In the zero-inflated portion of the model (not shown in Table 5), ECF did not differentiate between zero and non-zero scores (IRR = 1.06, $p = .93$), suggesting that ECF did not differentiate between participants with and without one or more alcohol-related problems. In the negative binomial portion of the model, ECF was not a significant predictor of number of alcohol-related problems among drinkers (IRR = 0.79, $p = .13$).

Sensitivity Analysis: Addressing relatively low levels of alcohol consumption in the sample.

We did not find evidence to support our hypotheses of an association between poor early-adolescent ECF and young-adult alcohol misuse and alcohol-related problems. One possible reason for the null associations is that there were relatively low levels of drinking in the sample. For example, 28% of the sample never drank, compared with 18% of a nationally-representative sample of young adults ages 19-24 (Johnston, O'Malley, Bachman, Schulenberg, & Miech, 2015).

We attempted to address this in three ways. First, in analyses of binge drinking, we lowered the threshold for binge drinking from 4+ drinks for women and 5+ drinks for men to 3+ drinks (for both sexes), and we re-computed the association between ECF and

binge drinking using this new, lower threshold. Results are shown in **Supplemental Table 4**. Early-adolescent ECF did not predict past-year drinking episodes of three or more drinks in young adulthood (β = 0.12, *p* = .38), after controlling for age, sex, and family history of AUD..

Second, we restricted the sample to participants whose mothers reported having an AUD in their lifetime, as parental AUD (and maternal AUD in particular) has been linked to heavy drinking (Bucholz et al., 2017). In accord with previous research, participants in the present study whose mothers had a personal history of AUD showed higher rates of heavy drinking than participants whose mothers did not have a personal history of AUD (e.g., 2.54 vs. 2.14 mean past-year binge drinking; Cohen's *d* = 0.28). Due to the small number of participants whose mother reported having AUD in their lifetime (n = 107; 46% of the full sample), we could not fit a latent ECF factor. Therefore, we examined the associations between individual ECF tasks and young-adult peak drinks, binge drinking, and alcohol-related problems using linear regression, with each outcome treated as an ordered categorical variable. Results are shown in **Supplemental Table 5.** Lower LNS (updating) predicted greater past-year binge drinking in young adulthood (β = -0.21, *p* = .002). This association remained statistically significant after controlling for family history of DUD, IQ, and early-adolescent externalizing behavior (β = -0.22, *p* = .006). Moreover, lower IMT (inhibition) predicted greater peak drinks in a day in young adulthood (β = -0.26, *p* = .010), which also remained statistically significant after controlling for family history of DUD, IQ, and early-adolescent externalizing behavior (β = -0.23, *p* = .024). All other associations

between early-adolescent ECF tasks and young-adult alcohol outcomes were not statistically significant.

Third, we restricted the sample to only those participants who were age 21 or older (i.e., legal drinking age) at the young-adult assessment. As with the analyses above, we could not fit a latent ECF factor due to the small number of participants who were age 21+ at follow up (n=77). Thus, we examined individual ECF tasks. All alcohol outcomes were treated as ordered categorical variables. **Supplemental Tables 6-8** show prospective associations between individual ECF tasks and each of the three drinking outcomes – peak drinks, binge drinking, and alcohol problems, respectively – in the subsample of participants ages 21+. In general, there were no associations between each of the three ECF tasks and each of the three drinking outcomes, after controlling for age, sex, and family history of AUD, with one exception: lower IMT (inhibition) was related to greater peak drinks in adulthood (β = -0.38, p = <.001). This statistically significant association remained after controlling for family history of DUD, IQ, and externalizing behavior (β = -0.40, p = <.001).

Sensitivity Analysis: Do individual ECF tasks predict heavy drinking and alcohol-related problems?

It is possible that the relation between ECF and risky drinking is specific to a particular ECF domain. For example, response inhibition may be a stronger predictor of risky drinking and alcohol-related problems than updating. Therefore, we examined the prospective associations between each individual ECF task and young-adult alcohol misuse and alcohol-related problems.

Supplemental Table 9 presents the prospective associations between individual ECF tasks and peak number of drinks in a day, after controlling for age, sex, and family history of AUD. Early-adolescent performance on the LNS and MST tasks, which tap the ECF domain of updating, was not significantly associated with young-adult peak number of drinks in a day. However, low scores on the IMT, which taps inhibition, prospectively predicted higher peak number of drinks in a day in young adulthood (IRR = 0.33, *p* =.001), over and above covariates of age, sex, and family history of AUD. The IRR suggests that for every one unit increase in the IMT there was a 77% decrease in peak drinks in a day. We then added covariates of family history of DUD, IQ, and early-adolescent externalizing behavior to determine whether poor IMT performance predicted peak drinks in a day after controlling for these factors. Low scores on the IMT prospectively predicted higher peak drinks in a day after adding covariates of family history of DUD, IQ, and externalizing behavior (IRR = 0.38, *p* =.006).

Supplemental Table 10 shows the prospective associations between individual ECF tasks and young-adult binge drinking, after controlling for age, sex, and family history of AUD. Model 1 shows associations between ECF tasks and past-year binge drinking among participants who have had a drink in their lifetime (n = 167); Model 2 tests whether ECF tasks predicted the odds of having one more past-year binge drinking episodes in the full sample (N = 232). All associations between early-adolescent performance on individual ECF tasks and young-adult binge drinking were statistically non-significant.

Supplemental Table 11 shows the prospective associations between individual ECF tasks and young-adult alcohol-related problems. Like in analyses of latent ECF, we

analyzed the data in two ways. Model 1 shows the association between ECF and alcohol-related problems (after controlling for age, sex, and family history of AUD) using linear regression among individuals who had ever had a drink (structural zeros removed). This model shows that individual ECF task performance did not predict young-adult alcohol-related problems (LNS: $\beta = 0.15$, $p = .053$; MST: $\beta = -0.03$, $p = .67$; IMT: $\beta = 0.03$, $p = .82$). Model 2 shows the association between ECF and alcohol-related problems in the full sample using zero-inflated negative binomial regression, after controlling for age, sex, and family history of AUD. In the zero-inflated portion of the model, individual ECF tasks did not predict the likelihood of having one or more alcohol-related problems (LNS: IRR = 0.98, $p = .94$; MST: IRR = 1.75, $p = .16$; IMT: IRR = .68, $p = .57$). Further, individual ECF task performance did not predict a count of the number of young-adult alcohol-related problems (LNS: IRR = 0.96, $p = .43$; MST: IRR = .27, $p = .16$; IMT: IRR = .64, $p = .56$).

Sensitivity Analysis: Addressing risk taking under the influence of alcohol.

Due to the link between ECF and risk taking (Steinberg, 2008), we wondered if ECF deficits would predict risk taking behavior under the influence of alcohol. Our measure of alcohol-related problems was comprised primarily of questions tapping alcohol dependence (e.g., "withdrawal", "strong urge or craving", "felt like you depended on it"; **Supplemental Table 12**), but a few items appeared to assess risk taking under the influence of alcohol (i.e., "arrested for drunk driving," "arrested for anything other than drunk driving," "having an accident or injury [while intoxicated]," and "injuring someone else [while intoxicated]." Of the 232 participants in the sample, 21 endorsed one or more alcohol-related risk taking items.

Supplemental Table 13 shows the prospective associations between ECF and the odds of engaging in one or more alcohol-related risk taking behaviors among individuals who had ever had a drink . Analyses controlled for age, sex, and family history of AUD. Latent ECF and individual ECF tasks did not predict the odds of engaging in alcohol-related risk taking behavior.

Discussion

This study tested the prospective association between ECF in early adolescence and alcohol misuse and alcohol-related problems in young adulthood. We hypothesized that adolescents with lower ECF would be more likely to misuse alcohol and have alcohol-related problems as young adults. However, we found little evidence to support this hypothesis. Early-adolescent ECF, represented by a latent factor indicated by both updating and inhibition tasks, and the individual ECF tasks themselves, were generally unrelated to alcohol misuse and alcohol-related problems in young adulthood. This was true in the full sample, in subsamples of heavier drinkers, and in the subsample of youth with a family history of AUD. Findings suggest that low ECF may not be a robust risk factor for alcohol misuse or alcohol-related problems.

This study contributes to already mixed findings in this area. Although several prospective studies have found evidence of an association between early-adolescent ECF deficits and subsequent drinking (Khurana et al., 2013; Peeters et al., 2015; Squeglia et al., 2014), others have not (Boelema et al., 2016; Norman et al., 2011; Squeglia et al., 2013; Wetterhill et al., 2013). There could be several explanations for the mixed findings. First, two of the three studies reporting positive findings assessed early drinking milestones in adolescent samples (e.g., age of drinking initiation) (Khurana et al., 2013;

Peeters et al., 2015). It is possible that low ECF is a relatively specific risk factor for early initiation of drinking and other early drinking milestones. Second, studies that found that ECF deficits predicted alcohol misuse tended to have shorter follow-ups. Generally speaking, correlations are highest among adjoining time points (Guttman, 1954). Thus, null findings in the present study may be related to our longer follow up. Lastly, mixed findings may be related to the use of different ECF tasks across studies (Day et al., 2015).

Though latent ECF did not generally predict alcohol outcomes after controlling for age, sex, and family history of AUD, some evidence suggested the predictive value of inhibition deficits. Specifically, analyses of individual ECF tasks showed that poorer performance on a task of inhibition (IMT), but not tasks of updating (LNS, MST), prospectively predicted a higher number of peak drinks in a day, independently of family history of a substance use disorder, IQ, and early-adolescent externalizing behavior. Present findings are consistent with a previous study in which poorer baseline performance on a task of inhibition at ages 12-14, but not other ECF tasks, predicted higher follow-up peak drinks on an occasion and more days of drinking at ages 17-18 (Squeglia et al., 2014). Furthermore, even in the absence of task performance differences, neuroimaging studies found that atypical brain activation during inhibition tasks predicted later alcohol use and alcohol-induced blackouts (Norman et al., 2011; Wetterhill, Castro, Squeglia, & Tapert, 2013). Taken together, inhibition deficits, assessed both through task performance and through neural imaging during inhibition tasks, could potentially serve as markers of risk for certain types of alcohol misuse.

Additionally, the present study found some evidence of a relation between pre-existing LNS deficits and past-year binge drinking among a subsample of participants whose mothers reported having an AUD in their lifetime (n = 107). Poor LNS task performance predicted past-year binge drinking in young adulthood; moreover, this association remained statistically significant after controlling for family history of DUD, IQ, and early-adolescent externalizing behavior. This suggests that different ECF components (e.g., inhibition, updating) may be differentially related to different types of alcohol misuse (e.g., peak drinks, binge drinking).

The present study has several limitations. First, participants retained at follow-up had higher IQ (K-BIT) and ECF (LNS, IMT) in early adolescence than those who did not complete the young-adult follow-up. Differential attrition may have attenuated associations between early-adolescent ECF and young-adult alcohol misuse and alcohol-related problems. However, effect-size differences between included and excluded participants on cognitive measures were small (d = .20-.35) (Cohen, 1988). Second, rates of drinking in the present sample were relatively low. Compared with a nationally-representative sample of young adults ages 19-24, participants in the present study were more likely to be lifetime alcohol abstainers (28% in this sample vs. 18% nationally), and less likely to have engaged in binge drinking in the past year (40% in this sample vs. 62% nationally) (Johnston, O'Malley, Bachman, Schulenberg, & Miech, 2015). Relatively low levels of drinking may have reduced statistical power to detect effects.

Third, our three ECF tasks only tapped two components of ECF: updating and inhibition. Other components, such as set-shifting, initiation, planning, and organizing, were not assessed. Thus, it is possible that other aspects of ECF not assessed here may

predict alcohol misuse and alcohol-related problems. Fourth, we hypothesized that ECF would predict alcohol-related problems, in part, because of its association with risk taking behavior; however, our measure of alcohol-related problems was primarily composed of questions tapping symptoms of dependence (e.g, "withdrawal," "strong urge or craving," "felt like you depended on it"). We attempted to address this limitation by selecting only those items tapping risk taking under the influence of alcohol (e.g., drunk driving), but few items remained (4 items) and few participants endorsed those items (n = 21). Future studies should use a more comprehensive measure of risk taking under the influence of alcohol. Nonetheless, null findings regarding the full alcohol-related problems measure are consistent with null findings from the only other study to examine the association between early-adolescent ECF and young-adult alcohol problems (Boelema et al., 2015). Lastly, some evidence suggests that repeated episodes of heavy drinking are associated with ECF decline (see Montgomery, Fisk, Murphy, Ryland & Hilton, 2012, for review), and substantial evidence shows that alcohol has acute negative effects on ECF (Boha et al., 2009; Fillmore et al., 2009; Montgomery et al., 2011; Marczinski & Fillmore, 2005). Because we only assessed ECF prior to drinking initiation, we were not able to investigate effects of drinking on ECF.

The present study has implications for research and theory. In terms of research, it might be most useful to consider the components of ECF separately. Although ECF has been hypothesized to be "greater than the sum of its parts" (Giancola, 2000), we found that a task of inhibition, but not a latent ECF factor or tasks of updating, predicted follow-up peak drinks in a day. Future studies might consider utilizing a latent inhibition factor comprised of three or more inhibition tasks. This could allow researchers to address the

"task impurity problem" while maintaining specificity in their investigation of particular executive components. In terms of theory, present findings warrant further investigation into inhibition as a core underlying mechanism of alcohol problems. Inhibition, which represents an inability to override a dominant response or natural inclination, might be more predictive of alcohol misuse than other aspects of ECF, including updating and shifting. For example, we found that poor inhibition was related to a greater number of peak drinks in a day, suggesting that individuals with poor inhibition may have difficulty limiting their alcohol consumption. In general, inhibition tasks show good validity, have well-mapped neural bases, and are predictive of a range of problem behaviors (Wiebe, Sheffield, & Espy, 2012). Moreover, the capacity of response inhibition to be assessed at various units of analysis, including in animal models (Hardung et al., 2017), make it a candidate domain for an "Alcohol Addiction RDoC" (Litten, 2015).

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Table 1. Descriptive statistics for all variables.

	N	Min	Max	Mean / %	SD
Early Adolescent Covariates					
Age	232	11	14	11.89	1.10
Gender (% Female)	232	--	--	48.9	--
Ethnicity (% Caucasian)[a]	232	--	--	52.3	--
SES (Family income)	204[b]	0	450,000	68,179	49,399
Family History Density of AUD	231	0	1.75	0.58	0.47
Family History Density of DUD	229	0	1.50	0.36	0.41
Externalizing Behavior	223	0	50	7.61	7.58
IQ	232	66	132	105.54	11.96
ECF Tasks					
Letter-Number Sequencing	232	6	25	18.11	2.93
Matrix Span Task	232	0.17	0.97	0.56	0.15
IMT	232	0.03	0.98	0.58	0.20
Young-Adult Follow-Up					
Age	232	18	24	19.68	1.72
Peak Drinks in a Day	232	0	30	6.25	6.88
Past-Year Binge Drinking[c]	232	1	7	2.34	1.68
Lifetime Alcohol-Related Problems	232	0	22	1.5	2.88

Note. a. Percentage Caucasian is presented because only Hispanic and non-Hispanic Caucasian families were recruited to the original study.

b. N's ranged from 204 to 232 because some parents did not know or chose not to reports their family income before taxes.

c. Past-year binge drinking was coded on a scale from 1-8 with "Never" (1), "1-2 times in my life" (2), "3-5 times in my life" (3), "More than 5 times, but less than once a month" (4), "1-3 times a month" (5), "1-2 times a week" (6), "3-5 times a week" (7), and "Every day" (8).

Table 2. Prospective associations between early-adolescent ECF and young-adult peak number of drinks in a day (n=232).

	Peak Drinks In a Day			
Predictor	b[c]	95% CI	β/IRR[c]	p-value
Model 1[a]				
Latent ECF	-0.10	(-0.27, 0.06)	-0.13	.21
Model 2[b]				
Latent ECF	-0.13	(-0.32, 0.06)	0.88	.17

Note. Analyses controlled for age, sex, and family history of AUD.
a. Model 1 was conducted using linear regression in Mplus and peak drinks was treated as an ordered categorical outcome. β is reported.
b. Model 2 was conducted using negative binomial regression in MPLUS, with peak drinks treated as a continuous count variable. The IRR is reported.
c. b = unstandardized coefficient; β = standardized coefficient; IRR = Incidence Rate Ratio.

Table 3. Prospective association between early-adolescent ECF and young-adult past-year binge drinking (n=167).

	Binge Drinking			
Predictor	b[a]	95% CI	β[a]	p-value
Latent ECF	0.07	(-0.14, 0.28)	0.09	0.51

Note. The analysis controlled for age, sex, and family history of AUD.
Note. The analysis was conducted using linear regression in Mplus and binge drinking was treated as an ordered categorical outcome. Non-drinkers were removed from the analysis (n=65).
a. b = unstandardized coefficient; β = standardized coefficient.

Table 4. Prospective association between early-adolescent ECF and the odds of binge drinking in the past year (N = 232).

	Odds of Binge Drinking			
Predictor	b[a]	95% CI	OR[a]	p-value
Latent ECF	-0.21	(-0.29, 0.11)	0.81	0.30

Note. The analysis controlled for age, sex, and family history of AUD.
Note. The analysis was conducted using the CATEGORICAL function in Mplus and binge drinking was treated as a binary variable (0 = did not binge drink, 1 = engaged in binge drinking).
a. b = unstandardized coefficient; OR = odds ratio.

Table 5. Prospective associations between early-adolescent ECF and lifetime alcohol related problems.

		Alcohol-Related Problems		
Predictor	b[c]	95% CI	β/IRR[c]	p-value
Model 1[a] (n=167)				
Latent ECF	0.07	(-0.27, 0.06)	0.09	0.49
Model 2[b] (n=232)				
Latent ECF	-0.24	(-0.32, 0.06)	0.79	0.13

Note. Analyses controlled for age, sex, and family history of AUD.

a. Model 1 was conducted linear regression in Mplus and alcohol-related problems was treated as an ordered categorical outcome. Non-drinkers (n=65) were removed from the analysis. β is reported.

b. Model 2 was conducted using zero-inflated negative binomial regression in MPLUS. The IRR is reported. Non-drinkers (n=65) were included in the analysis.

c. b = unstandardized coefficient; β = standardized coefficient; IRR = Incidence Rate Ratio.

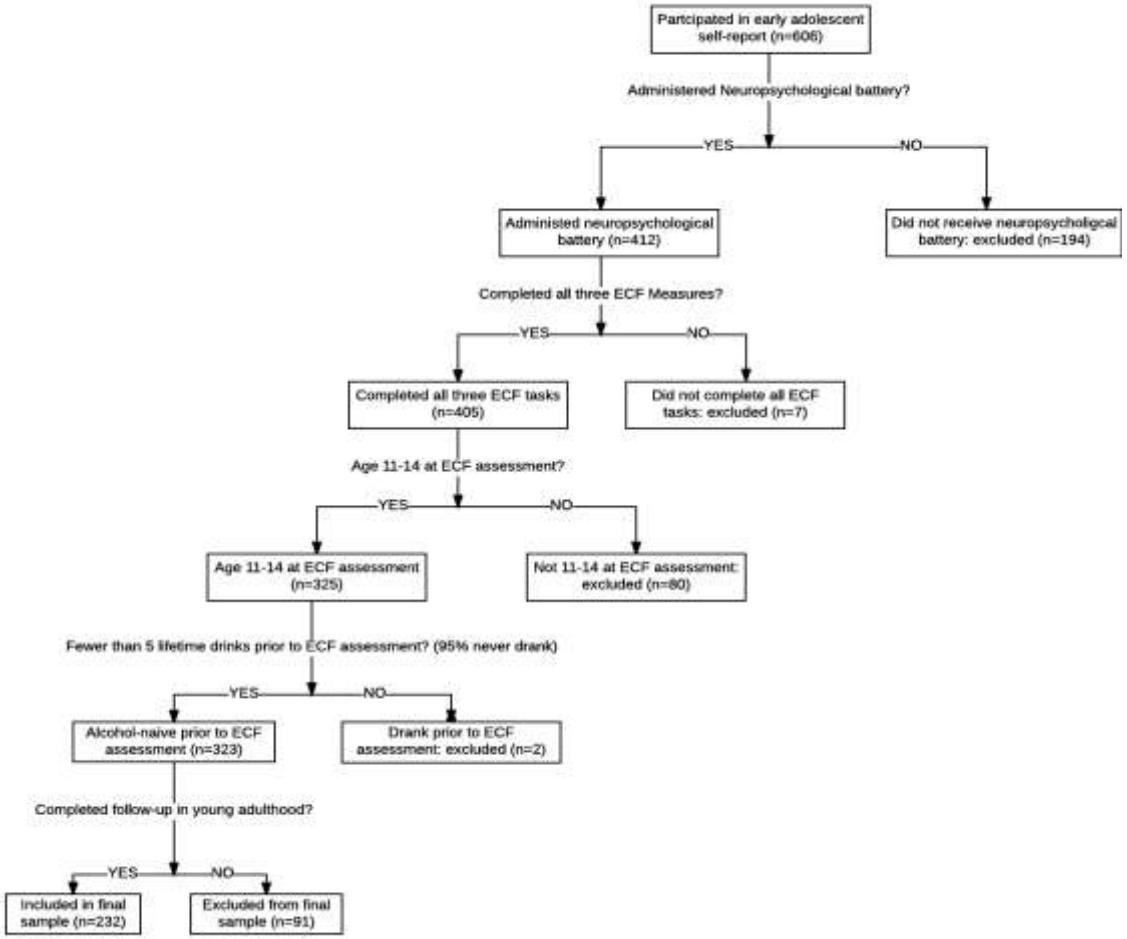

Figure 1. Study flow starting at ECF assessment.

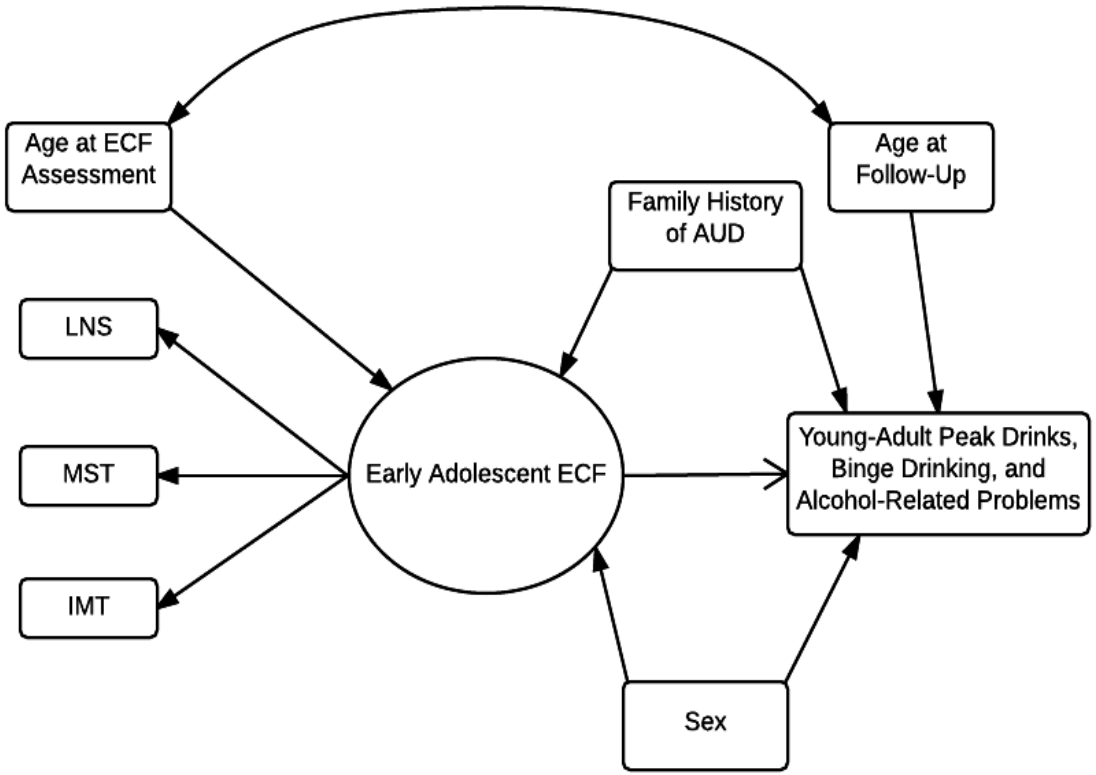

Figure 2. Basic path model of early-adolescent ECF predicting young-adult peak drinks, binge drinking, and alcohol-related problems.Young-adult peak drinks, binge drinking, and alcohol-related problems were considered separately.

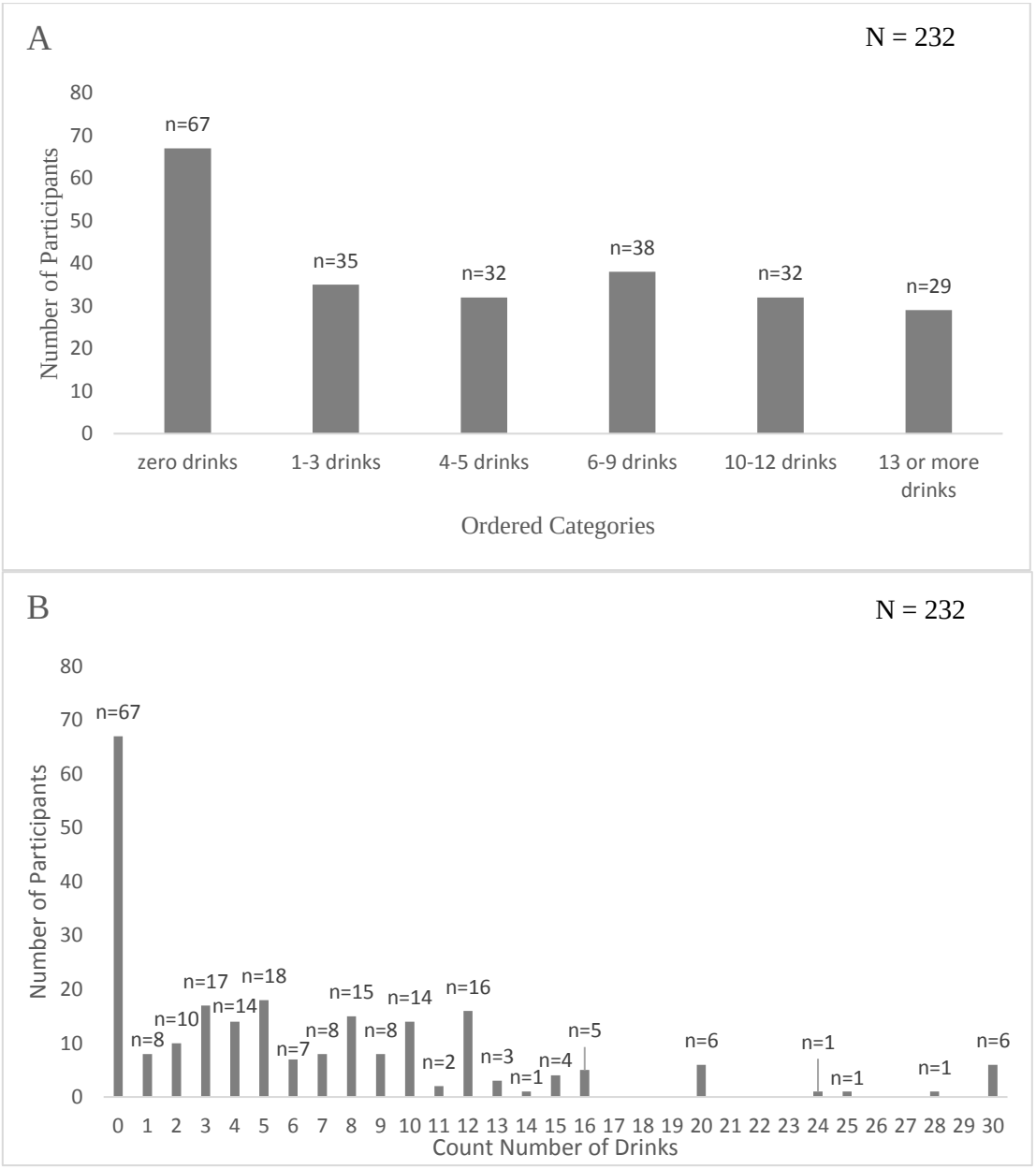

Figure 3. Ordered categorical (Panel A) and count distribution (Panel B) of lifetime peak number of drinks in a day. Participants who reported drinking more than 30 drinks in a single day (n=6) were recoded to 30 drinks based on lethal limits of alcohol consumption.

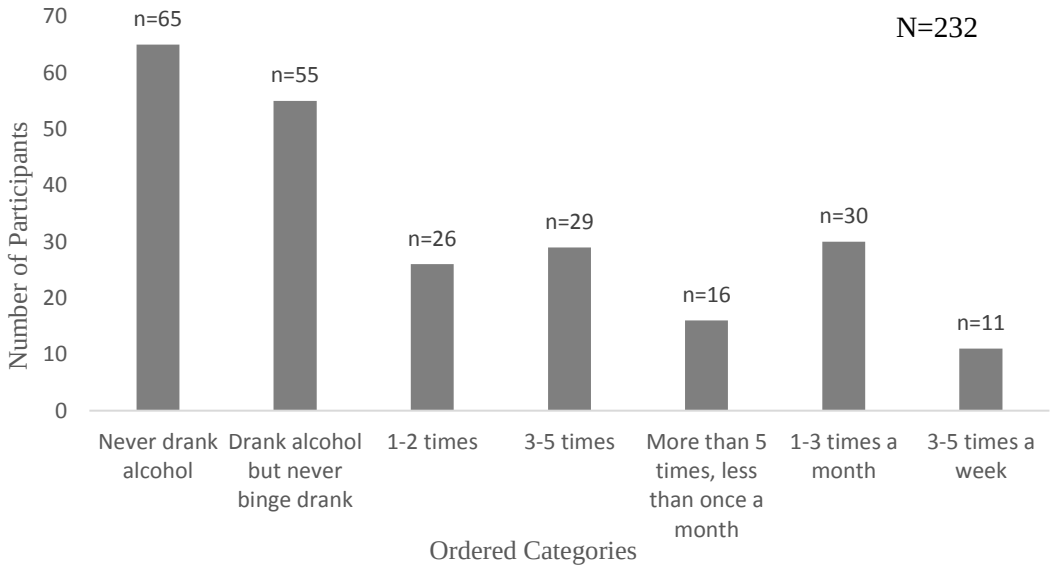

Figure 4. Ordered categorical distribution of past-year binge drinking. Participants who never drank alcohol (n=65) were removed from the distribution prior to analysis.

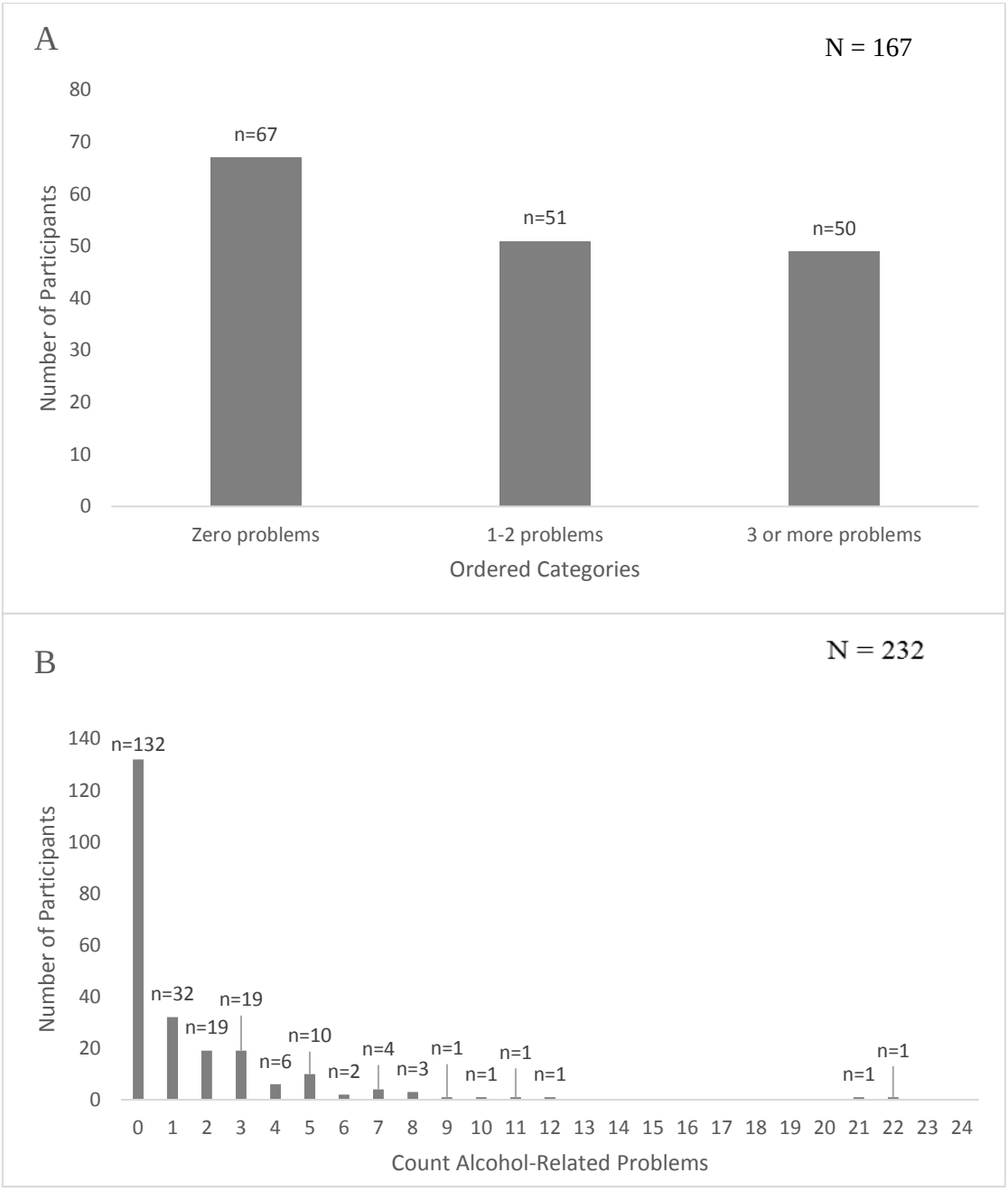

Figure 5. Ordered categorical (Panel A) and count distribution (Panel B) of lifetime alcohol-related problems. Participants who never drank in their lifetime (n=65) were removed from the ordered categorical distribution (Panel A) prior to analysis.

Supplemental Table 1. Comparison between included and excluded participants.

	Included		Excluded		Comparison		
Adolescent Variables	***N***	***Mean (SD) / %***	***N***	***Mean (SD) / %***	**Cohen's d**	***t-statistic/ Chi-Square***	***p-value***
Age at ECF Assessment	232	11.89 (1.10)	91	11.95 (1.14)	0.05	0.49	.56
Sex (% Female)	232	48.91	90	40.00	--	2.09	.15
Ethnicity (% Caucasian)	232	52.34	90	53.33	--	0.03	.87
SES	204	68,179 (49,399)	79	69,794 (40,004)	0.04	0.22	.82
Family History Density of Lifetime AUDs	231	0.58 (.47)	87	0.61 (.48)	0.06	0.54	.59
Family History Density of Lifetime DUDs	229	0.36 (0.41)	87	0.37 (0.40)	0.02	0.32	.75
Externalizing Behavior (Ages 11-14)	223	7.61 (7.58)	83	7.99 (7.80)	0.05	0.39	.75
IQ (Ages 11-14)	232	105.5 (11.96)	91	102.2 (11.68)	-0.28	-2.42	**.016**
Letter-Number Sequencing	232	18.11 (2.93)	91	17.11 (2.78)	-0.35	-2.91	**.004**
Matrix Span Task (Ages 11-14)	232	0.56 (0.15)	91	0.53 (0.15)	-0.20	-1.45	.15
Immediate Memory Task (Ages 11-14)	232	0.58 (0.20)	91	0.52 (0.20)	-0.30	-2.40	**.017**

Note. N's vary because participants were missing data on some variables.

Supplemental Table 2. Zero-order correlations between ECF tasks and peak drinks, binge drinking, and alcohol-related problems.

Predictor/Outcome Variables	1.	2.	3.	4.	5.	6.
1. Letter-Number Sequencing	--	0.43*	0.24*	0.04	0.01	0.12
2. Matrix Span Task		--	0.32*	0.05	-0.02	0.01
3. Immediate Memory Task			--	-0.06	0.09	-0.02
4. Peak Drinks in a Day				--	0.75*	0.60*
5. Past-Year Binge Drinking					--	0.56*
6. Alcohol-Related Problems						--

Note. All ECF tasks were coded so higher scores indicate better executive functioning.
*p<.01

Supplemental Table 3. Zero-order correlations between covariates and predictor/outcome variables.

	Predictor Variables			Outcome Variables		
Covariates	LNS	MST	IMT	Peak Drinks	Binge Drinking	Alcohol Problems
Age at ECF Assessment	0.27**	0.27**	0.37**	0.27**	0.26**	0.15*
Sex	-0.17**	0.13*	-0.18*	0.06	0.02	0.05
Ethnicity	-0.06	-0.06	-0.01	0.06	0.04	-0.01
Family Income	-0.02	-0.02	-0.04	-0.06	-0.06	-0.01
Family History of AUD	-0.15*	-0.24**	-0.01	0 .24**	0.23**	0.09
Family History of DUD	-0.04	-0.06	0.03	0.19**	0.16*	0.18**
IQ	0.40**	0.30**	0.16*	-0.19	-0.13*	-0.04
Externalizing Behavior	-0.06	-0.01	-0.17*	0.09	-0.05	0.07
Age at Follow-up	0.25**	0.30**	0.27**	0.40**	0.34**	0.24**

Note. 0 = female and 1 = male; 0 = Caucasian and 1 = Hispanic/Other ethnicity
**p<.01, *p<.05

Supplemental Table 4. Prospective associations between early-adolescent ECF and young-adult binge drinking, defined as 3+ drinks (n=167).

	3+ Drinks in an Occasion			
Predictor	b[a]	95% CI	β[a]	p-value
Latent ECF	0.09	(-0.11, 0.28)	0.12	.38

Note. The analysis included only participants who consumed an alcoholic drink in their lifetime. It was conducted using linear regression in Mplus and binge drinking was treated as an ordered categorical outcome, and controlled for age, sex, and family history of AUD.
a. b = unstandardized coefficient; β = standardized coefficient.

Supplemental Table 5. Prospective associations between ECF tasks and young-adult peak drinks, binge drinking, and alcohol-related problems among those whose parents had an AUD in their lifetime (n = 107).

	Peak Drinks				Binge Drinking				Alcohol-Related Problems			
Predictor	b[c]	95% CI	β[c]	p	b[c]	95% CI	β[c]	p	b[c]	95% CI	β[c]	p
LNS	-0.05	(-0.11, 0.01)	-0.12	.11	**-0.09**	**(-0.14, -0.03)**	**-0.21**	**.002**	0.07	(-0.01, 0.17)	0.22	.10
MST	-0.49	(-1.69, 0.71)	-0.07	.42	-0.66	(-2.01, 0.69)	-0.10	.34	-0.56	(-1.88, 0.76)	-0.08	.41
IMT	**-1.32**	**(-2.31, -0.32)**	**-0.26**	**.010**	-0.50	(-1.53, 0.54)	-0.10	.35	0.31	(-0.97, 1.58)	0.06	.64

Note. Analyses were conducted using linear regression in Mplus and treated peak drinks, binge drinking, and alcohol-related problems as ordered categorical outcomes. All participants whose mothers had a history of AUD were included in analyses. Analyses controlled for age, sex, and family history of AUD.

a. b = unstandardized coefficient; β = standardized coefficient; IRR = incidence rate ratio.

Supplemental Table 6. Prospective associations between individual ECF tasks and young-adult peak number of drinks in a day among participants ages 21 years or older (n=77).

					+ controlling FH of DUD[a]		+ controlling IQ		+ controlling externalizing	
ECF Task	b[b]	95% CI	β[b]	p-value	β[b]	p-value	β[b]	p-value	β[b]	p-value
LNS	-0.02	(-0.10, 0.05)	-0.06	.55	--	--	--	--	--	--
MST	0.14	(-1.28, 1.55)	0.02	.85	--	--	--	--	--	--
IMT	-1.95	(-3.02, -0.88)	-0.38	**<.001**	-0.37	**.001**	-0.41	**<.001**	-0.40	**<.001**

Note. All analyses controlled for age, sex, and family history of AUD.
a. FH of DUD = family history of drug use disorder.
b. b = unstandardized coefficient; β = standardized coefficient.
Dashes indicate the estimate was not calculated because the previous model was non-significant.

Supplemental Table 7. Prospective associations between individual ECF tasks and young-adult past-year binge drinking among participants ages 21 years or older (n=71[b]).

	Binge Drinking			
ECF Task	b[a]	95% CI	β[a]	p-value
LNS	-0.02	(-0.10, 0.05)	-0.06	.55
MST	-0.05	(-0.15, 0.06)	-0.13	.37
IMT	0.48	(-0.74, 1.70)	0.10	.44

Note. All analyses controlled for age, sex, and family history of AUD.
a. b = unstandardized coefficient; β = standardized coefficient.
b. Individuals who never drank (n=6) were dropped from the analysis

Supplemental Table 8. Prospective associations between individual ECF tasks and young-adult alcohol-related problems among participants ages 21 years or older (n=71[b]).

	Alcohol-Related Problems			
ECF Task	b[a]	95% CI	β[a]	p-value
LNS	0.06	(-0.04, 0.16)	0.16	.27
MST	-0.33	(-1.87, 1.22)	-0.05	.68
IMT	-0.24	(-1.51, 1.03)	-0.05	.71

Note. Analyses controlled for age, sex, and family history of AUD.
a. b = unstandardized coefficient; β = standardized coefficient.
b. Individuals who never drank (n=6) were dropped from the analysis

Supplemental Table 9. Prospective associations between individual ECF tasks and young-adult peak number of drinks in a day (n=232).

						+ controlling FH of DUD		+ controlling IQ		+ controlling externalizing	
ECF Task	Model	b	95% CI	β/IRR	p-value	β/IRR	p-value	β/IRR	p-value	β/IRR	p-value
LNS	Model 1[a]	0.01	(-0.05, 0.05)	0.01	.92	--	--	--	--	--	--
	Model 2[b]	0.02	(-0.03, 0.06)	1.02	.43	--	--	--	--	--	--
MST	Model 1	-0.15	(-1.04,0.75)	-0.02	.75	--	--	--	--	--	--
	Model 2	-0.29	(-1.32,0.78)	0.75	.59	--	--	--	--	--	--
IMT	Model 1	-0.92	(-1.54,-0.30)	-0.17	**.003**	-0.17	**.004**	-0.15	**.016**	-0.14	**.032**
	Model 2	-1.10	(-1.72,-0.48)	0.33	**.001**	0.32	**>.001**	0.35	**.002**	0.38	**.006**

Note. All analyses controlled for age, sex, and family history of AUD.
a. Model 1 was conducted using path analysis in Mplus and treated peak drinks as an ordered categorical outcome. β is reported.
b. Model 2 was conducted using negative binomial regression in MPLUS. The IRR is reported.
Note. b = unstandardized coefficient; β = standardized coefficient; IRR = incidence rate ratio.
Dashes indicate the estimate was not calculated because the previous model was non-significant.

Supplemental Table 10. Prospective associations between early-adolescent ECF and young-adult past-year binge drinking.

		Binge Drinking		
ECF Task	b[c]	95% CI	β/OR[c]	p-value
Model 1[a]				
LNS	-0.01	(-0.07, 0.06)	-0.01	.89
MST	-0.59	(-1.77, 0.79)	-0.07	.46
IMT	0.46	(-0.41, 1.32)	0.09	.30
Model 2[b]				
LNS	-0.05	(-0.16, 0.05)	0.95	.33
MST	-1.28	(-3.29, 0.73)	0.28	.21
IMT	0.27	(-1.26, 1.80)	1.31	.73

Note. Analyses controlled for age, sex, and family history of AUD.

a. Analyses included only participants who consumed an alcoholic drink in their lifetime (n=167). Analyses were conducted using linear regression in Mplus and binge drinking was treated as an ordered categorical outcome. β is reported.

b. Analyses included the full sample (N=232). Binge drinking was treated as a binary outcome of those who did (0) and did not (1) binge drink in the past year. The OR is reported.

c. b = unstandardized coefficient; β = standardized coefficient; OR = odds ratio.

Supplemental Table 11. Prospective associations between individual ECF tasks and young-adult alcohol-related problems.

		Alcohol-Related Problems			
ECF Task	Model	b[c]	95% CI	β/IRR[c]	p-value
LNS	Model 1[a]	0.05	(-0.01, 0.10)	0.15	.053
	Model 2[b]	-0.04	(-0.14, 0.06)	0.96	.43
MST	Model 1[a]	-0.22	(-1.22, 0.79)	-0.03	.67
	Model 2[b]	-1.32	(-3.13, 0.50)	0.27	.16
IMT	Model 1[a]	0.11	(-0.82, 1.04)	0.03	.82
	Model 2[b]	-0.44	(-1.96, 1.07)	0.64	.56

Note. All analyses controlled for age, sex, and family history of AUD.

a. Model 1 was conducted using linear regression in Mplus and treated peak drinks as an ordered categorical outcome (n=167). β is reported.

b. Model 2 was conducted using negative binomial regression in MPLUS (n=232). The IRR is reported.

c. b = unstandardized coefficient; β = standardized coefficient; IRR = incidence rate ratio.

Supplemental Table 12. Twenty-four item measure of alcohol-related problems.

1. How recently has your alcohol use caused you to get complaints from your family or friends?
2. How recently have you tried to cut down on alcohol but found out you couldn't?
3. How recently have you felt guilty about your drinking?
4. How recently did your alcohol use cause you to spend little time with your family?
5. How recently did your alcohol use cause you to lose friends?
6. How recently did your alcohol use cause you to get arrested for drunk driving?
7. How recently did your alcohol use cause you to get arrested for anything other than drunk driving?
8. How recently did your alcohol use cause you to get into financial trouble?
9. How recently did your alcohol use cause you to have illnesses or physical problems?
10. How recently did your alcohol use cause you to give up important activities?
11. How recently did your alcohol use cause you to have an accident or injury?
12. How recently did your alcohol use cause you to injure someone else?
13. How recently did your alcohol use cause you to have problems with your family or friends?
14. How recently did your alcohol use cause you to have problems on the job or in school?
15. How recently did your alcohol use cause you to lose your temper with your family?
16. How recently did your alcohol use cause you to miss work or school?
17. How recently did your alcohol use cause you to lose a job or get kicked out of school?
18. How recently have you awakened the morning after drinking and found that you could not remember part of the evening before?
19. How recently has there been a period when you spent so much time arranging to get alcohol or having it in your mind so much that you had little time for anything else?
20. How recently have you ended up using much larger amounts of alcohol than you expected to when you began, or over more days than you intended to?
21. How recently have you used alcohol enough so that you felt like you needed it or depended on it?
22. How recently have you had withdrawal symptoms (that is, you have felt sick) because you stopped or cut down on alcohol?
23. How recently have you had difficulty stopping after several drinks when you wanted to?
24. How recently did you feel a strong urge or craving for alcohol?
Note. Bolded items were used in analysis of alcohol-related risk taking.

Supplemental Table 13. Prospective associations between individual ECF tasks and alcohol-related risk taking (N = 167[a]).

		Alcohol-Related Risk Taking		
ECF Measure	b[b]	95% CI	OR[b]	p-value
Latent ECF	-0.04	(-0.67, 0.58)	0.96	.90
LNS	0.03	(-0.13, 0.20)	1.03	.70
MST	0.80	(-2.67, 4.24)	2.22	.65
IMT	-0.50	(-2.96, 1.97)	0.61	.69

Note. All analyses controlled for age, sex, and family history of AUD.
Note. Alcohol-related risk taking was measured as a latent variable comprised of 4 items.
a. Of the 167 participants who had ever had a drink in their lifetime, 21 endorsed one or more risk-taking items.
b. b = unstandardized coefficient; OR = odds ratio.